DAQ for Hyper-K Water Cherenkov detectors

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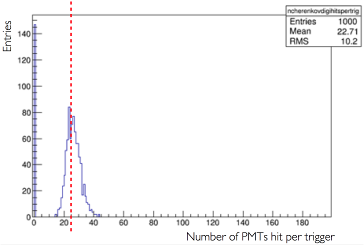
Outline

1. Software
   - Simulation
   - Low-energy triggering
2. Hardware
3. Summary

WCSim: simulating water Cherenkov detectors

- There were problems with the dark noise, digitizer, & trigger
  - Trigger efficiency too high at low energy
    - Trigger used raw hits, instead of digits
  - Difficult to perform studies on digitizer/trigger effects



- Rewrote to fix issues, and made it modular
  - Can now easily study new triggers (& digitizers)
- Other improvements:
  - Overlay radioactivity on physics events
  - Upgrade from `Geant4.9.x` to `Geant4.10.x`

Data rates in HK 40%

Data source	Event rate	Hits/event	Raw data rate
Dark noise	10 kHz	1 (per tube)	5 GB/s
Low energy backgrounds	10 kHz	25	3 MB/s
Cosmic muons	100 Hz	40,000	50 MB/s
Beam	1 Hz	0	0 MB/s
Calibration	2 Hz	40,000	2 MB/s
Pedestal	1 Hz	40,000	2 MB/s

- Dark noise dominates the raw data
  - Want to reduce this as much as possible, without sacrificing physics
  - Leads to cheaper DAQ system
    - Less hardware: easier to scale
    - Less storage: 5 GB/s = 18 TB/hour = 13 PB/month
    - Less CPU time to reconstruct events / analyse the dataset

How SK triggers: NHITS

1. Count number of hits in a sliding time window
   - Window size ≈ max light travel time across detector

L1 If NHITS > threshold, issue trigger

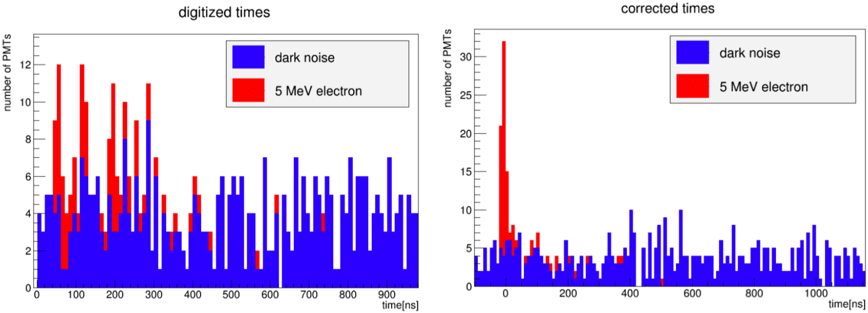
L2 If NHITS > a lower threshold, perform full reconstruction to decide to trigger

	SK	HK 14%	HK 40%
Max light travel time (ns)	200	400	400
NPMTs	11146	14728	44028
PMT dark rate (kHz)	4.2	8.4	8.4
Noise hits in trigger decision window	$\sim$9	$\sim$49	$\sim$148

- There are so many background hits in HK 40%!
- Are there clever ways to trigger without performing full reconstruction?

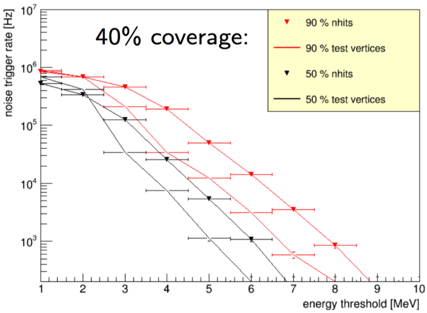
Test-vertices L2 trigger

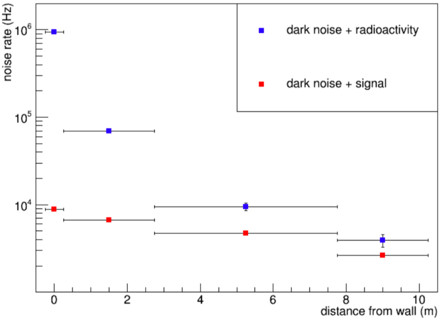
- Populate detector with cylindrical array of test-vertices ($\Delta L = 5$ m)
- For each vertex, apply photon time-of-flight correction, then proceed with NHITS-like trigger
  - Reduces trigger time window: 400 ns $\rightarrow$ 20 ns
  - $\sim$vertex reconstruction to kill dark noise
    - ⋆ 5 MeV e^- vertex resolution: position 2.1 m; time 13 ns



Test-vertices L2 trigger performance

- Process in real-time on $\sim$100 GPUs
  - Currently <$400,000 (should become cheaper)
- For a given noise trigger rate, the test-vertices algorithm lowers the trigger threshold by $\sim$1 MeV
- Can cut PMT radioactivity by rejecting events with reconstructed vertices at detector edges
  - Suppress 87% PMT radioactivity with 30% total volume loss





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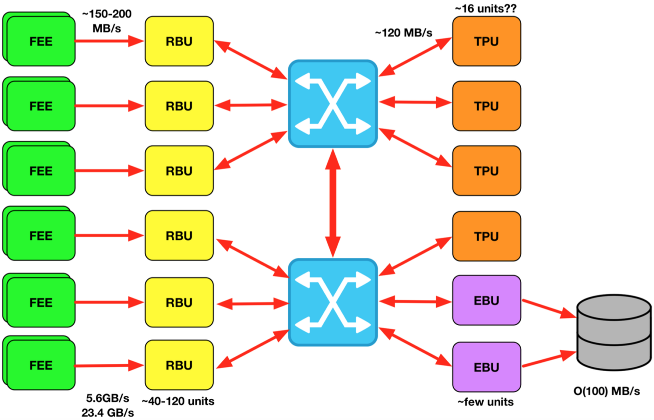
DAQ reference design

- Physics studies used as input to design
  - Ongoing, two-way process

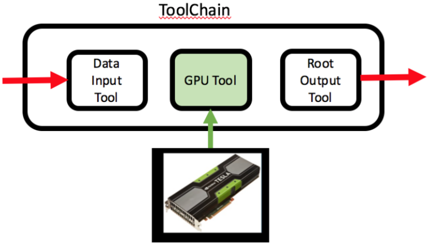


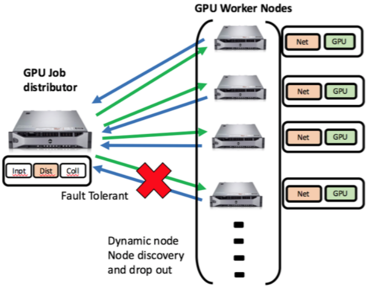
FEE: Front-End Electronics
RBU: Readout Buffer Unit

TPU: Trigger Processing Unit
EBU: Event Building Unit

DAQ framework

- Many options for a DAQ framework
  - `artdaq`, `MIDAS`, written ourselves, ...
- Currently doing tests using `ToolDAQ`
  - Developed in UK for HK as a fault-tolerant, lightweight, DAQ framework
  - Currently being used by the ANNIE experiment
  - Designing HK & intermediate detector layout





Summary

- Improved `WCSim`
- Studying some new L2 trigger algorithms for HK 40%
  - Test vertices lowers energy threshold by ∼1 MeV
  - Other triggers are being studied
- TITUS *should* be easier
  - Fewer lower-noise (smaller) PMTs, but more cosmics
  - Will perform detailed studies when a combined near detector design has been chosen
- Have a baseline DAQ hardware design
- Weighing up pros & cons of different DAQ frameworks
  - Including our bespoke code (`ToolDAQ`)

Backups

4 DAQ design

DAQ design

Use physics studies & prototype measurements to design the DAQ

1. Event rates and triggering
2. Detector readout requirements
3. Data storage
4. Functionality
5. Detector monitoring

Key aspects

1. Raw data rate
    - In particular raw data rate in the event of a local supernova
2. Triggered event data rate
    - This depends on where the triggers are implemented
        - Firmware of the electronics and/or in the DAQ computer
3. Triggered architecture
    - What firmware etc will we use.

DAQ design

1. Event types and triggering
   1. Successfully access the majority of physics of interest.
   2. Have the ability to handle event rates.
   3. Discard non-physics events using a trigger.
   4. Sufficient local storage/processing to deal with events from a local supernova.

DAQ design

2. Detector readout requirements

1. Handle incoming data from multiple compartments.
2. Deal with cross-compartment triggers.
3. Readout rate will depend on where the triggers are implemented i.e. in electronics firmware or on a backend system.
4. Design includes a setup such that if one node fails it will automatically run on another node. Investigate cloud like setup?

DAQ design

3. Data storage
   1. Transfer of data from the DAQ machines to disk.
   2. Transfer of data offsite.
   3. Run numbering scheme.

DAQ design

4. Functionality

1. Should be easy to use for non-experts.
2. Have the ability to run compartments independently (e.g. for calibration).
3. Read out of additional calibration information.

DAQ design

5. Detector monitoring

1. Successfully access the majority of physics of interest.
2. Have the ability to handle event rates.
3. Discard non-physics events using a trigger.
4. Sufficient local storage/processing to deal with events from a local supernova.
5. Near time checks will have to be made on the incoming data to ensure that the detector is performing satisfactorily.
6. Monitoring of electronics/PMTs e.g. temperature, voltage etc. This should use a separate readout stream to the data.